# A Fault-tolerant Algorithm for Adaptive Control Mode of Traffic Signal Controller

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***Abstract***

Adaptive control mode is an important function of traffic signal controller. It is also a necessary requirement of the development of intelligent transportation system (ITS). The real-time data collection of traffic flow is the foundation of the adaptive control mode. Aimed at solving the problems that the data exceptions and loss of the vehicle detectors are caused by noise interferences or communication failure, this paper proposes a fault-tolerant algorithm based on least squares support vector regression(LS-SVR). The algorithm can estimate the traffic flow while the corresponding detectors malfunction. Thus the basis data can be offered for the adaptive control mode of traffic signal controller. The simulation results demonstrate the validity of the proposed algorithm.

***Keywords***

*Traffic Signal Controller; Vehicle Detector; Fault-Tolerant Algorithm; Adaptive Control; LS-SVR*

## Introduction

According to the real-time traffic flow, adaptive traffic control mode of traffic signal controller achieves optimal timings of traffic signal, which can adapt to dynamic traffic flow and meet the requirements of the development of intelligent transportation system. The current traffic adaptive signal control systems are mainly centralized control modes. The timing plan of an area is generated in remote control center and transmitted to each traffic signal controller through the network. This mode not only leads to high computational load of the remote control center, but network communication failure will seriously affect the normal operation of the adaptive control. Optimal timing for adaptive control mode realized independently by traffic signal controller can overcome the above drawbacks.

Adaptive control mode of traffic signal controller depends on dynamic traffic flow data. The degraded operation will be carried out if the vechicle detector malfunctions. In order to ensure the adaptive control mode even when the detector failures, this paper propose a fault-tolerant algorithm based on least squares support vector regression (LS-SVR). The algorithm can estimate the traffic flow while the corresponding detectors malfunction. Thus the basis data can be offered for the adaptive control mode of traffic signal controller.

The fault-tolerant algorithm is based on short-term traffic flow prediction. Short-term traffic flow prediction methods include linear prediction, nonlinear prediction, and hybrid prediction methods, etc. Linear prediction methods include historical average model (Stephanedes Y.J., etc., 1981), time series model (Zhu Shunying, etc., 2003), the state space model (Ye Zhirui, etc., 2006). The methods such as average, difference, likelihood estimation and least squares are mostly used in Linear prediction, which has the advantages of simplicity and fastness. However, it is difficult to reflect the dynamic uncertainty and nonlinear characteristics of traffic flow, especially unable to overcome random disturbance factors.

Nonlinear prediction methods include nonparametric regression (Clark, Stephen, 2003), neural network (Ishak. S., etc.) and support vector machine regression (Yao Zhisheng, etc., 2006). Assuming that related information of transport system is implicated in the historical data, nonparametric regression algorithm tries to find the similarities from the historical data, and to predict the traffic flow of next time according to the similarity. Nonparametric regression prediction is more accurate than parametric modeling method when a special event occurs. But nonparametric regression methods need a lot of historical data, and thus have high computational complexity. Neural network can learn from historical data, which has the advantage of

adaptability. But its result is based on empirical risk minimization principle. Therefore, neural network has the drawbacks such as over learning and local minima. LS-SVR is a class of machine learning algorithms based on structural risk minimization. Due to the fast calculation speed and global optimum, LS-SVR can be used to predict the traffic flow of any adjacent lane. Hybrid forecasting methods can integrate different prediction methods to improve prediction. However, there is no universal combination model which is suitable for adaptive control mode.

Considering the advantages and disadvantages of the above-mentioned traffic flow prediction methods, we propose a fault-tolerant algorithm based on LS-SVR for the adaptive control mode. In LS-SVR, regularization parameter determines the trade off between prediction precision and computational cost. K-fold cross-validation method is one of the most common methods for the selection of regularization parameter of LS-SVR. But this method is not suitable for the implementation in traffic signal controller because of its high computational complexity. In our work, sigmoid function is introduced into to select the regularization parameter adaptively. This method not only guarantees the accuracy of prediction, but also reduces the computational complexity significantly. The simulation results demonstrate the validity of the algorithm.

## Principle of Fault-Tolerant Strategy

### *The Architecture of Traffic Signal Controller*

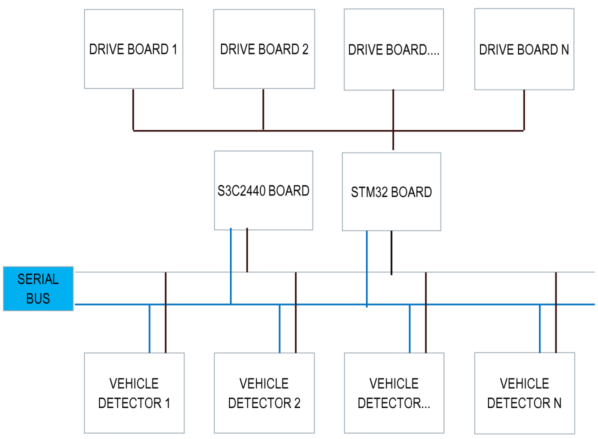


FIG. 1 THE ARCHITECTURE OF TRAFFIC SIGNAL CONTROLLER

Adaptive signal control mode needs to optimize timing plan dynamically which requires very high computing power. Therefore, our work is based on platform of distributed traffic signal controller (shown in Fig.1). Typical structure of the traffic signal controller consists of S3C2440 based master control module, STM32 control module, driver module and vehicle detector module, etc. Among which ARM9 core chip S3C2440 is the main control unit, it implements the optimization of signal timing according to traffic flow from vehicle detector. STM32 micro processor is responsible for performing the timing plan coming from main controller.

### *Overview of Adaptive Control Mode of Traffic Signal Controller*

Based on the real-time traffic volume acquired from vehicle detector, Adaptive control mode of traffic signal controller optimizes timing and performs the optimal signal control program of road intersection. In adaptive control mode, split is also optimized according to coordinate cycle and offset. Adaptive control mode of traffic signal controller is Real-time, dynamic and the closed loop control.

Vehicle detector is one of the important equipments for detecting real-time traffic volume, and it is the foundation of adaptive control mode of traffic signal controller. In urban road traffic system, vehicle detector is easily affected by interference such as hardware malfunction, noise interferences and communication faults. This will lead to data exception and data loss, which greatly affects the function of adaptive control mode. Thus, we focus on the fault-tolerant strategy in adaptive control mode in this paper.

## Fault-Tolerant Algorithm

### *Fault-Tolerant Algorithm Description*

Typically, there are two classes of vehicle detector malfunction. One class is that vehicle detector fault occurs in only one road lane (shown in Fig.2).

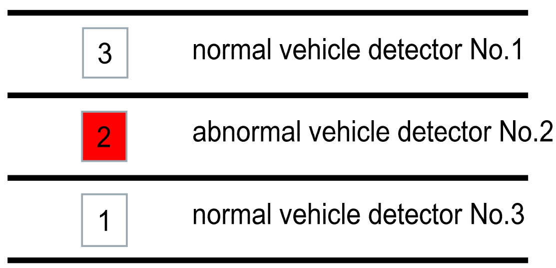


FIG.2 FAULT OCCURS IN ONLY ONE ROAD LANE

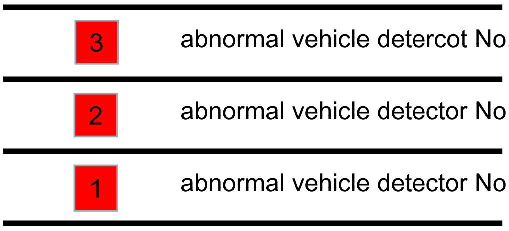


FIG.3 ABSENCE OF TRAFFIC VOLUME IN ALL LANES IN ONE ROAD SECTION

Another class is the absence of traffic volume because the vehicle detectors in all lanes malfunction simultaneously. We focus our effort on solving the general case (shown in Fig.3)

Considering the situation shown in Fig, 3, because traffic volume has certain stability during the short time, traffic volume at fault moment can be short-term predicted according to the historical data. As traffic volume has the features of uncertainty and nonlinearity, linear forecasting method is difficult to meet the requirements. Meanwhile, to meet the computer power and storage capacity of traffic signal controller, small samples for traffic volume predicting should be selected. LS-SVR is an effective methodology to solve the problem of small sample and nonlinear regression. In this paper, LS - SVR is chosen for short-term traffic volume predicting.

The performance and complexity of LS-SVR crucially depends on the choice of regularization parameter C and kernel parameter $\sigma$ . K- fold cross-validation method, the grid search method, parameter genetic algorithm and particle swarm algorithm are commonly used in optimal selection of the LS-SVR parameters. Due to the limitation of computing and storage capabilities of traffic signal controller, the above mentioned methods are not suitable for predicting traffic flow. In this paper, sigmoid method is chosen for optimizing regularization parameter of LS-SVR.

According to the sigmoid parameter optimization selection method, regularization parameter C is related to the variation range of traffic volume. Considering noise data contained in training sample, regularization parameter C is small when the traffic volume is small. On the contrary, the regularization parameter C is large when the traffic volume is large in order to gain a higher approximation accuracy. Regularization parameter C in LS-SVM is determined using:

$$C_i = (y_{\max} - y_{\min})\frac{1-e^{-y_i}}{1+e^{-y_i}} + y_{\min} \tag{1}$$

with the possible maximum $y_{\max}$ and minimum traffic volume $y_{\min}$ in training sample set.

In addition, as one of the most classical kernel functions, RBF function is chosen as the kernel function

$$K(x_i, x_j) = \exp\left(-\left\|x_i - x_j\right\|^2 / \sigma^2\right) \tag{2}$$

where $\sigma$ represents the width of the kernel. In this work, we choose $\sigma = 0.3 * range\|x\|$.

Algorithm steps are described as follows:

Step1. while vehicle detector malfunctions, use the history traffic flow (the time interval is 5 minutes) from the corresponding lane to train LS-SVR,. Suppose the sample size is n.

Step2. all sample points are denoted as $x_1, x_2, \cdots x_n$, these sample points are divided into m groups. sample points $(X_1, Y_1), (X_2, Y_2), \cdots (X_m, Y_m)$ ,where $X_1 = (x_1, \cdots x_{n-m})$ , $Y_1 = x_{n-m+1}$, $X_2 = (x_2, \cdots x_{n-m+1})$ , $Y_2 = x_{n-m+2}, \cdots$, $X_m = (x_m, \cdots x_{n-1})$ , $Y_m = x_n$ .

optimize kernel parameter $\sigma$ and regularization parameter C using 10-fold cross-validation method and sigmoid method respectively.

Step3. let $xIn = (x_{m+1}, x_{m+2}, \cdots x_n)$ be an input vector, estimate traffic volume of fault occurring with LS-SVR.

Step4. Add the new fitting results to the training sample and remove the earliest sample point, Scroll to carry out step2, step3

Step5. terminate the algorithm until all training samples are used.

### *Analysis of Algorithm Complexity*

Due to the fault-tolerant algorithm is carried out in traffic signal controller, high complexity of algorithm will affect normal running of the traffic signal controller. The computational complexity of our algorithm is $o(n^3)$ , which depends on LS-SVR. In the distributed traffic signal controller (shown in Fig.1), the execute time of our algorithm is relevant with the search scope of $\sigma$ ,C , the number of training sample and S3C2440 instruction cycle.

Assume that the search scope of $\sigma$ ,C are *r1* and *r2*,the search step size are *s1* and *s2*. the number of training

sample is $n$, and the instruction cycle is $p$. The running time of S3C2440 for LSSVR with 10-fold cross-validation method is expressed:

$$t = (10*\frac{r1}{s1}*\frac{r2}{s2}*n^3 + n^3)*\frac{1}{p} \tag{3}$$

The running time of LS-SVR with sigmoid method is relevant with the number of training sample and S3C2440 instruction cycle.

$$t = n^3 * \frac{1}{p} \tag{4}$$

Using sigmoid method for parameter optimal selection can decrease the calculation time considerably. For instance, the running time is about 70 $\mu s$ if n equals to 24.

## Experimental Results

Some road section in Hefei City is selected to be research object. the road is two-way six lanes and the total length are 300 meters. We select the vehicle detector data (the time interval is 5minutes, 48 groups) on April 15,2013, 15:00-19:00 to validate our algorithm. Use vehicle detector data from 15:00 to 17:00 as training samples, and data form 17:00 to 17:30 as validate samples. The parameters of the LS-SVR are optimized with 10-fold cross-validation method and sigmoid method respectively. RMSE, MAE and MAPE were utilized as evaluation indexes.

$$RMSE = \sqrt{\frac{1}{l}\sum_{i=1}^{l}(y_i - f(x_i))^2} \tag{5}$$

$$MAE = \frac{1}{l}\sum_{i=1}^{l}\left|y_i - f(x_i)\right| \tag{6}$$

$$MAPE = (\frac{1}{l}\sum_{i=1}^{l}\left|\frac{y_i - f(x_i)}{y_i}\right|)\times 100\% \tag{7}$$

TABLE 1. ESTIMATION RESULTS OF TRAFFIC VOLUME WITH DIFFERENT METHODS OF LS-SVR

| Evaluation Index | RMSE | MAE | MAPE |
|---|---|---|---|
| Lane 1(10-fold ross-validation) | 3.9487 | 3.3786 | 10.99% |
| Lane 1 (Sigmoid) | 3.9485 | 3.3784 | 10.99% |
| Lane 2(10-fold cross-validation) | 5.7981 | 4.5859 | 5.65% |
| Lane 2 (Sigmoid) | 5.8307 | 4.6208 | 5.7% |
| Lane 3(10-fold cross-validation) | 4.7531 | 3.8128 | 23.76% |
| Lane 3 (Sigmoid) | 4.5786 | 3.7315 | 23.55% |

The results show that after vehicle detectors malfunction happened, our algorithm can estimate the traffic volume with less than 10% mean absolute percentage error until half an hour. As time goes on, MAPE will become bigger. Besides, the results respectively using 10-fold cross-validation method and sigmoid method are almost similar. However, the complexity of sigmoid method is much smaller. Because of the regularity and periodic of traffic flow, the results will be better if the history information is considered.

## Conclusion

Aimed at vehicle detectors malfunction of traffic signal controller, this paper proposed a fault-tolerant algorithm, which can make the adaptive control mode work normally even when vehicle detector malfunctions. In order to meet the requirements of real-time in embedded systems, sigmoid method is introduced to optimize the LS-SVR parameters. Our algorithm significantly can reduce the computational complexity, and is suitable for application to embedded system platform.

## ACKNOWLEDGMENT

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## REFERENCES

Clark Stephen. “Traffic prediction using multivariate nonparametric regression”. Journal of Transportation Engineering, 2003,129(2): 161-165.

Fan Xiaoxue. “Least square support vector machine parameter selection”. Hebei University,2012.

Feng Chen, Dali Wei, Yongning Tang. “Virtual Ion Selective Electrode for Online Measurement of Nutrient Solution Components”. Sensors Journal, IEEE, 2011, 11(2): 462 – 468.

GONG Xiao-yan, TANG Shu-ming. “Integrated traffic flow forecasting and traffic incident detection algorithm based on non-parametric regression”. China Journal of Highway and Transport, 2003,16(1):82-86.

GU Yanping, ZHAO Wenjie, WU Zhansong. Least squares support vector machine algorithm. J Tsinghua Univ(Sci&Tech), 2010,Vol.50, No.7.

Ishak S., Kotha P., Alecsandru C.2003. “Optimization of

dynamic neural network performance for Short-term traffic prediction". Transportation Research Record1836: 45-56.

J. A.K.Suykens,J. Vandewalle. "LeastSquares Support Vector Machine classifiers". Neural Processing Letters, 1999,9(3):293–300.

LIU Liang-ping, JIA Li-ming, QIN Yong, DONG Hong-hui, SUN Xiao-Liang, XU Dong-wei. "Data Collection and Failure Detection of Traffic Flow". LOGISTICS TECHNOLOGY , 2010,29(8):47-49.

LUO Yun-qian, XIA Jing-bo, WANG Huan-bin. "Application of Chaos-support Vector Machine Regression in Traffic Prediction". Computer Science, 2009,30 (7):244-246.

Nie Lei,Yang Xiao Guang,Ma Wan Jing,Lin Yu,Yuan Chang Liang,Sheng Feng. Design and Software Implementation of Urban Isolated Intersection Real-time Adaptive Control System, 2006.

O.Chapella,V. Vapnik,O.Bousquet,et al. "Choosing multiple parameters for support vector machines". Machine Learning, 2002,46(1):131-159.

Stephanedes Y. J., Michalopoulos P. G., Plum R.1981. "A.Improved estimation of traffic flow for real-time control". Transportation Research Record 795: 28-39.

Tehao Zhu. "The Initiative Area Coordination Control for Urban Traffic Network.". Hefei,University of Science and Technology of China, 2012.

WANG Xing-Ling, LI Zhan-Bin. "Identifying the Parameters of the Kernel Function in Support Vector Machines Based on the Grid-Search Method". Periodical of Ocean University of China, 2005,5:859-86.

YAO Zhi-sheng, SHAO Chun-fu, GAO Yong-liang. "Research On Methods of Short-Term Traffic Forecasting Based on Support Vector Regression". Journal of Beijing Jiaotong University, 2006, 30(3):19-22.

YAO Zhi-sheng, SHAO Chun-fu, XIONG Zhi-hua. "Research on Short-Term Traffic Flow Combined Forecasting Based on Wavelet Package and Least Square Support Vector Machines". Chinese Journal of Management Science. 2007,15(1):64-68.

Ye Zhirui, Zhang Yunlong, Middleton Dan R. "Middleton. Unscented Kalman filter method for speed Estimation using single loop detector data". Transportation Research Record, 1968,2006: 117-125.

ZHU Shun-ying ,WANG Hong ,LI Guan-shou. "The ARIMA Model Used in Forecasting of Traffic Volume in Short Interval on the Link". JOURNAL OF CHONGQING JIAOTONG UNIVERSITY,2003, 22(1):76-77.